PART II

DETAILED CLASSIFICATION PROCEDURES

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4.0 CLASSIFICATION PROCEDURES

The previous sections provide both background and overview of the EPA ground-water classification system. The system is based on an analysis of data which is generally available from published sources, telephone or in-person contacts, or other program-related sources, such as permit packages and environmental impact statements. The need for detailed information on the hydrogeologic or socioeconomic properties of an area will increase, for example, where a Class I or Class III designation is possible, or a subdivision of ground waters in the Classification Review Area is being considered. In the majority of decisions, data gathering and interpretation will be simple and inexpensive.

This chapter provides a more in-depth discussion of the actual process of site-by-site classification. The process is facilitated through a classification procedural chart shown in Figure 4-1. A corresponding classification "worksheet" (Table 4-1) follows the sequence of procedural chart steps. Classification will typically begin with step one and continue until a final class determination is made. Both the procedural chart and worksheet were developed to provide a systematic approach to classifying ground water based on certain criteria, e.g., presence of wells, ecologically vital areas, water quality, irreplaceability, etc. They are provided as suggested approaches only, since a given setting may be more effectively handled through another sequence of steps.

It is important to realize that, as a result of the classification procedure, the Agency is not classifying a specific ground-water region, per se. The classification process will assist the EPA programs in such activities as permitting and corrective-action assessments. No mapped unit will be generated, although a Classification Review Area will be employed as an aid in the decision process.

Lastly, the system assumes a broad definition for current use as a source of drinking water (IIA). In the absence of current use, the system will lead to a determination of potential source of drinking water (IIB), unless a lower resource value is demonstrated. Other beneficial uses of ground water will be considered in making Class II determinations.

FIGURE 4-1
PROCEDURAL CLASSIFICATION CHART

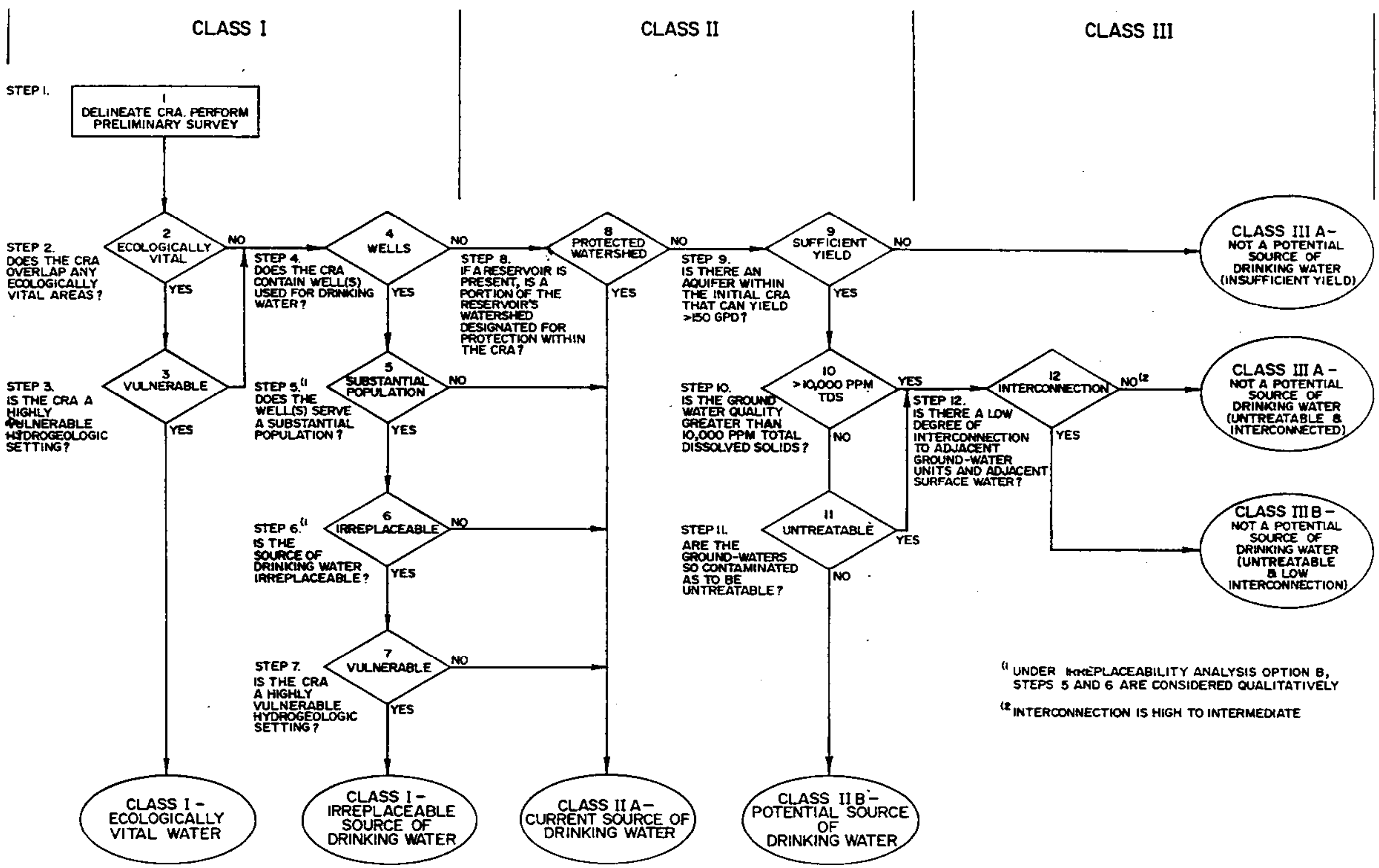


TABLE 4-1
CLASSIFICATION WORKSHEET

Step	Question/Direction	Response/Comment*
1	Establish Classification Review Area (CRA) and collect preliminary information. Optional-Demonstrate subdivision(s) of the CRA	
2	Locate any ecologically vital areas in the CRA.** Does the CRA or appropriate subdivision overlap an ecologically vital area? . Yes, go to next step . No, go to Step 4	
3	Perform vulnerability analysis. Is the CRA or appropriate subdivision a highly vulnerable hydrogeologic setting? . Yes, then the ground water is CLASS I-ECOLOGICALLY VITAL . No. go to next step	
4	Determine location of well(s) within the CRA or appropriate subdivision. Does the CRA or appropriate subdivision contain well(s) used for drinking water? . Yes, to to next Step . No, go to Step 8	

*To be completed when performing classification.
**Steps 2 and 3 may be performed in reverse order.

Step	Question/Direction	Response/Comment*
5*	Inventory population served by well(s). Does the well(s) serve a substantial population? . Yes, go to next step . No, then the ground water is CLASS IIA-CURRENT SOURCE OF DRINKING WATER	
6*	Unless proven otherwise, the drinking water source is assumed to be irreplaceable. Optional-perform irreplaceability analysis. Is the source of drinking water irreplaceable? . Yes, go to next step . No, then the ground water is CLASS IIA-CURRENT SOURCE OF DRINKING WATER	
7	Perform vulnerability analysis. Is the CRA or appropriate subdivision a highly vulnerable hydrogeologic setting? . Yes, then the ground water is CLASS I-IRREPLACEABLE SOURCE OF DRINKING WATER . No, then the ground water is CLASS IIA-CURRENT SOURCE OF DRINKING WATER	

*Under irreplaceability analysis Option B, Steps 5 and 6 are considered qualitatively.

Step	Question/Direction	Response/Comment*
8A	Determine location of reservoirs within the CRA or appropriate sub-division. Does the CRA or appropriate subdivision contain reservoirs used for drinking water? . Yes, go to next step . No, go to Step 9	
8B	Determine status of watershed(s) containing reservoir(s) present in the CRA or appropriate subdivision. Does that portion of the water-shed designated for water-quality protection overlap the CRA or appropriate subdivision. . Yes, then the ground water is CLASS IIA-CURRENT SOURCE OF DRINKING WATER . No, go to next step	
9	Determine yield from ground-water medium (total depth across CRA or appropriate subdivision). Can it yield 150 gallons-per-day to a well? . Yes, go to next step . No, then the ground water is CLASS IIIA-NOT A SOURCE OF DRINKING WATER (INSUFFICIENT YIELD)	

Step	Question/Direction	Response/Comment*
10	Determine water-quality characteristics within the CRA or appropriate subdivision. Is the water quality greater than 10,000 mg/l total dissolved solids (TDS)? (Note: If water quality is unknown, then this question must be answered no.) . Yes, go to Step 12 . No, go to next step	
11	Are the ground waters so contaminated as to be untreatable? (Note: If water quality is unknown, then this question must be answered no.) . Yes, go to next step . No, then the ground water is CLASS IIB-POTENTIAL SOURCE OF DRINKING WATER	
12	Perform interconnectedness analysis. Is there a low degree of interconnection between the ground water being classified and adjacent ground units or surface waters within the initial CRA? . Yes, then the ground water is CLASS IIIB-NOT A SOURCE OF DRINKING WATER (LOW INTERCONNECTION) . No, then the ground water is CLASS IIIA-NOT A SOURCE OF DRINKING WATER (INTERMEDIATE-TO-HIGH INTERCONNECTION)	

4.1 Preliminary Information

An overview of basic information needs for classification is presented in this section. More detailed discussions are provided in the balance of this chapter as well as in the Appendices. The collection of preliminary information is meant to reflect an approach to classification which begins simply and directly. The data should be collected from the most current and best available sources. It should include a well/reservoir survey, demographic information, and identification of ecologically vital areas. Regional hydrogeologic data will be required if an interconnection analysis needs to be made. Otherwise, a general description of the regional geology, geomorphology, and hydrogeology would be useful. Again, the emphasis is on available information rather than on detailed in-field analyses.

4.1.1 Base Map of Classification Review Area

The Classification Review Area is defined by drawing a two-mile radius from the boundaries of the facility or activity area. An expanded review area is allowed under certain hydrogeologic conditions of intermediate-to-high ground-water velocities. These conditions and the procedures to expand the Classification Review Area are presented in Section 4.2. This Classification Review Area may be subdivided based on a hydrogeological analysis of interconnection between adjacent surface waters and ground-water units as described in Section 4.3. A base map illustrating the facility location, and the Classification Review Area boundary is, of course, a vital piece of basic data.

4.1.2 Well Survey

A well survey should include the location, use, and pumpage capacity of existing public water-supply wells or well fields within the Classification Review Area. Public water-supply systems are defined under the Safe Drinking Water Act as those serving more than 25 persons or with more than 15 service connections. Information on the well depth and screened interval depth may be needed if a subdivision of the Classification Review Area is to be made.

A detailed inventory of private residential wells is not necessary. As pointed out in Section 4.4, census data (e.g., densly settled areas) can be a good estimation approach. As a preliminary step, the delineation of areas not served by public water supplies, and the approximate number or density of homes in the area should be obtained. The simplest well data to be included are the estimated number of wells present, and other general characteristics of private wells in the Classification Review Area.

Well information may be obtained from water authorities, public health agencies, regulatory agencies permitting well drilling, well drillers, or other state or local entities. Sources of the data should be documented and, where the information is not available, it should be so stated.

Water-supply reservoirs designated for water-quality protection in the Classification Review Area need to be identified and described. Again, state and local agencies may be utilized in this capacity. Water-supply reservoir watersheds designated for water-quality protection are specifically recognized in the ground-water classification system.

4.1.3 Demography

Information on populations served by public and private wells will be needed if it is apparent that substantial populations may be involved, which could lead to a Class I decision. A first-cut approximation for public supply wells in the area can be made by dividing the total pumpage capacity by the typical per capita consumption rates for the region. Estimates of the number of private wells in densely settled areas within the Classification Review Area will also be necessary. Densely settled areas can be located on U.S. Census Bureau maps. Procedures for determination of substantial population are provided in Section 4.4.

4.1.4 Ecologically Vital Areas

Identification of areas which may be candidate discharge points for ground water is a first step in locating ecologically vital areas. Such areas may include springs, streams, caves, lakes, wetlands, estuaries, coastlines, embayments, and playas. Once these candidate discharge areas have been identified (since proving discharge may require field studies), the presence of a habitat for a listed or proposed endangered or threatened species (pursuant to the Endangered Species Act as amended in 1982) needs to be examined. The location of any such areas, or any Federal lands managed for ecological values within the Classification Review Area must be identified. The Regional Office of the U.S. Fish and Wildlife Service and the State Endangered Species coordinator or Heritage Program administrator are two sources for information regarding unique habitats and/or endangered or threatened species. Information about Federal lands may also be obtained from Federal land management agencies such as the National Park Service, U.S. Forest Service, and Bureau of Land Management. The presence of Federal lands is indicated on most state and county road maps and U.S. Geological Survey quadrangle sheets.

4.1.5 Hydrogeologic Data

Regional hydrogeologic information will be needed, to some extent, in order to perform a DRASTIC analysis for the vulnerability criterion; estimates are needed on:

- depth to water
- net recharge
- uppermost aquifer media
- soil media
- topography (slope)
- vadose zone media
- hydraulic conductivity of the uppermost aquifer.

This information is typically reconnaissance in nature and may likely be obtained from county/regional reports and also State geologic surveys. Pertinent information will be obtained from U.S. Geologic Survey cross-sections, topographic maps, stratigraphic sections, county geologic maps, and U.S. Department of Agriculture soil maps.

If interconnectedness of ground water with adjacent ground units and surface waters is to be analyzed, additional detailed hydrogeologic information is necessary. This might include descriptive hydrogeologic data, aquifer test data from previous studies, semi-quantitative flow nets, computer simulations or other relevant information. This information is critical for all Class III demonstrations. Specific considerations for interconnection to adjacent water is described in Section 4.3.

The best available sources of published hydrologic/-geologic information are the U.S. Geological Survey publications, State geological surveys, scientific books and journals, and U.S. Department of Agriculture county soil surveys. Data supporting facility permit applications, Clear Water Act Section 208 studies, as well as Environmental Impact Statements, may also be useful.

4.2 Conditions and Procedures for Expanding the Classification Review Area

Expansion of the Classification Review Area is allowed under certain hydrogeologic conditions. The two-mile radius may be insufficient for determining the use and value of ground water and identifying potentially affected users in hydrogeologic conditions of intermediate to very high ground-water flow velocities where these velocities occur over distances much greater than two miles. In such settings, there is a potential for activity-related contaminants to move beyond a two-mile radius in a relatively short time frame, especially under the influence of large-scale ground-water withdrawals. This section represents qualitative descriptions of those hydrogeologic settings where an expanded review area is appropriate, and the procedures to quantitatively establish the dimensions of the expanded review area based on hydrogeologic characteristics.

An expansion of the Classification Review Area will be triggered upon the determination that the activity under review occurs within two hydrogeologic settings. Because these settings are described qualitatively, some level of hydrogeologic information will be needed to match the real settings to qualitative description.

4.2.1 Hydrogeologic Settings

Two hydrogeologic settings have been identified where expansion of the Classification Review Area is appropriate. They are:

A. Settings (referred to as Karst settings) where the principle aquifer is relatively shallow (<100m) and composed of carbonate rocks, with a well developed system of solution-enlarged openings (secondary porosity). The solution-enlarged openings serve as the main conduits for ground-water flow and are interconnected into distinct but dynamic ground-water basins feeding a complex of cave streams. These settings are often referred to as karst areas or karst aquifers. Flow through the conduit system is extremely rapid, as much as 1800 ft-per-hour (Quilan and Ewers, 1985) over long distances, in some cases up to 15 miles. Settings may be found in the following ground-water regions (after Heath, 1984):

6. Non-Glaciated Central Region
7. Glaciated Central Region
10. Atlantic and Gulf Coastal Plain Region
11. Southeast Coastal Plain Region, and
15. Puerto Rico and the Virgin Islands.

B. Certain settings (referred to as alluvial basin settings) where the general length of ground-water flow paths are significantly greater than the two-mile Classification Review Area radius (i.e., where the distance between perennial streams is greater than four miles). These settings are predominantly alluvial basins and other basins filled with unconsolidated to semi-consolidated materials and are, in addition, characterized by:

- An unconfined aquifer as the dominant aquifer
- Losing streams as the predominant source of recharge
- Transmissivities and flow velocities that are moderate to high (>250 m^2/d and >60 m/yr, respectively)
- Relatively low annual rain fall (less than 20 inches)

The ground-water regions (after Heath, 1984) where these settings can be found include:

2. Alluvial Basin Region
3. Columbia Lava Plateau Region
4. Colorado Plateau and Wyoming Basin Region
5. High Plains Regions, and
6. Non-Glaciated Central Region.

4.2.2 Expanded Classification Review Area Dimensions

The dimensions of the expanded review area are governed by the hydrogeologic characteristics of the region. Flow-system boundaries, flow direction, and flow velocities are the key characteristics.

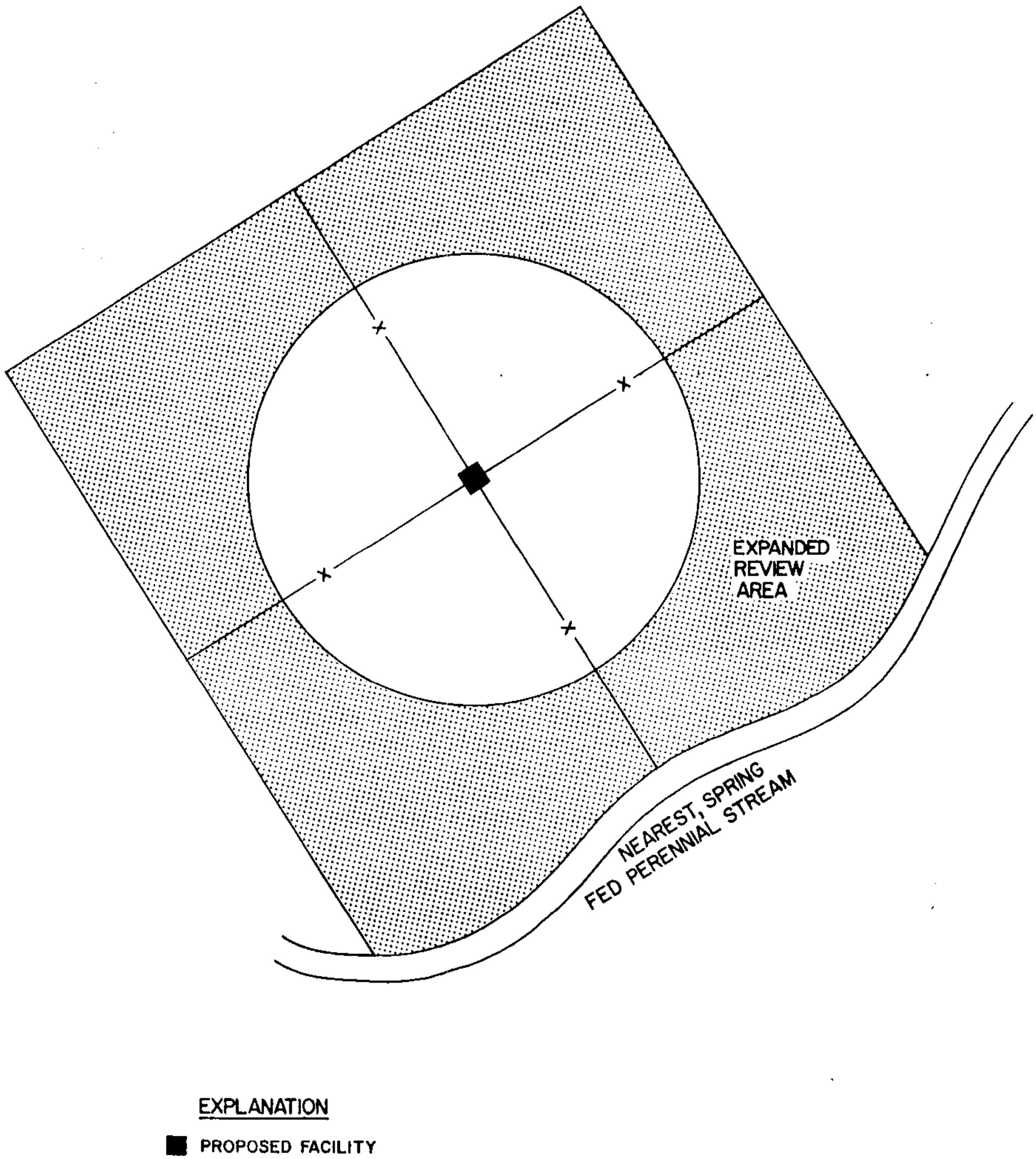
For Setting A, karst areas, the expansion area dimensions will be based on boundaries of the ground-water basin(s) encompassing the activity. A basin includes all recharge areas supplying the cave stream extending to the perennial stream where the cave-stream discharges. These basins can be mapped using dye-tracing studies and a water-level map. However, due to the expense of such studies, few basins have been mapped. As a surrogate, it is recommended that the distance to the nearest spring-fed, perennial stream be employed to establish the expanded review-area dimensions as shown in Figure 4-2. The reviewer is cautioned that, in some cases, the nearest perennial stream may not be the discharge for the subject ground-water basin. Such an error can be minimized by locating the topographic high (the water-shed divide) between the nearest perennial stream and adjacent streams. If the activity is on the same side of the topographic high as the nearest perennial stream, then it is reasonable to assume that the nearest perennial stream is the discharge. If not, then the discharge is likely to be the perennial steam on the same side of the topographic high as the activity/facility. In rare cases, the activity or facility is located on the topographic high. In such a case, the expanded review area should extend to the nearest perennial stream on all sides of the topographic high.

For Setting B, alluvial basins, the dimensions of the expanded review area are based on the average ground-water flow velocity within the basin. The radius is to be extended to a distance that ground water will flow in a period of 50 years. For example, if flow velocities averaged 400 feet-per-year, then the expanded radius would be 20,000 feet, approximately four miles. In the event that ground-water flow velocities are unknown, an expanded radius of five miles is recommended.

Ground-water flow velocities range over several orders-of-magnitude. The highest velocities are those of the karst cave streams. In alluvial basins, it will be unlikely that flow velocities as high as one mile a year will occur except over very short distances not representative of flow throughout the basin.

The dimensions of the expanded review area can be modified to account for the direction of flow. Where flow direction can be reliably determined, only the downgradient portion of the expanded review area need be examined. The expanded review area can also be subdivided according to rules outlined in Section 4.3. Examples of expanded Classification Review Area for both a Karst setting and an alluvial basin setting are provided in Appendix C case studies 10 and 11, respectively.

FIGURE 4-2
EXAMPLE OF GEOMETRY AND DIMENSIONS OF THE PROPOSED
EXPANDED REVIEW AREA FOR KARST SETTINGS



4.3 Subdivision of the Classification Review Area: Identification of Ground-Water Units and Analysis of Interconnection Between Ground-Water Units

The ground-water regime defined in Chapter 3.0 can be subdivided into three-dimensional, mappable ground-water units. The Classification Review Area, regardless of size, may be subdivided to allow more precise definition of the specific ground-water units where classification should be focused. This chapter presents the methods and examples by which subdivisions are identified and how the degree of interconnection between the subdivisions is analyzed.

Subdivision of a Classification Review Area may be carried out to separate ground-water units having different use and value and, therefore, are subject to different degrees of protection. For example, the subdivision of the Classification Review Area will be necessary to justify the following types of conclusions:

- Deep ground-water units with Class IIIB water are overlain at shallow depth by ground-water units with Class I or II water,
- The ground-water unit associated with an activity does not discharge to an ecologically vital area present in the Classification Review Area,
- A shallow, ground-water unit that is a potential source of drinking water (Class IIB) is underlain by a deeper ground-water unit that is currently used as a source of drinking water (Class IIA)

Having identified the ground-water units within the Classification Review Area, the user of this document is ready to classify the waters within the units in accordance with the methods set forth in other sections and schematically summarized in Figure 4-1. The interrelationship between ground-water unit subdivisions and the classification of ground water are as follows:

- All ground water within a ground-water unit has a single class designation.
- Boundaries separating waters of different classes must coincide with boundaries of ground-water units,

- One or more adjacent ground-water units may have the same class designation.

Ground-water units are delineated on the basis of three types of boundaries described below:

Type 1: Permanent ground-water flow divides. These flow divides should be stable under all reasonably foreseeable conditions, including planned manipulation of the ground-water regime.

Type 2: Extensive, low-permeability (non-aquifer) geologic units (e.g., thick, laterally extensive confining beds), especially where characterized by favorable hydraulic head relationships across them (i.e., direction and magnitude of flow across the low-permeability geologic unit). The most favorable hydraulic head relationship is where flow is toward the ground-water unit being classified and the magnitude of the head difference (hydraulic gradient) is sufficient to maintain this direction of flow under all foreseeable conditions. The integrity of the low permeability unit should not be interrupted by improperly constructed or abandoned wells, extensive, interconnected fractures, mine tunnels or other apertures.

Type 3: Permanent fresh water-saline water contacts (saline water defined as those waters with greater than 10,000 mg/l of Total Dissolved Solids). These contacts should be stable under all reasonably foreseeable conditions, including planned manipulation of the ground-water regime.

The degree of interconnection between ground-water units is related to the type of boundary. A high degree of interconnection is assumed for all waters within a single ground-water unit. Adjacent units that are separated by a Type 1 (ground-water flow divide) or Type 3 (fresh water-saline water contact) boundary have an intermediate degree of interconnection. Adjacent units separated by a Type 2 (low-permeability geologic unit) boundary have a low degree of interconnection.

The degree of interconnection across the three boundary types defined here depends on selected key physical and chemical processes governing movement of water and dissolved solute in the subsurface. Under steady/state ground-water flow conditions the principal mechanisms effecting potential contaminant movement across Type 1 (ground-water flow divide) or Type 3 (salinity difference) boundaries would be mechanical dispersion and chemical diffusion. These conditions are considered by EPA to represent an intermediate degree of interconnection. Under transient flow conditions caused by pumpage or accelerated recharge of fluids within the Classification Review Area, there exists the potential to spatially displace a ground-water flow divide or saline/fresh water interface boundary. For this reason EPA believes that foreseeable changes in aquifer stresses and increased ground-water use in the Classification Review Area should be considered in determining the permanence (i.e., location over time) of such boundaries.

The primary mechanism for contaminant transport across a Type 2 boundary is the physical movement of ground water into or from the low-permeability geologic unit. The Agency recognizes that the physical and chemical processes that control fluid and solute transport through low-permeability non-aquifers is not as well understood as it is for aquifers. However, for the purposes of assessing the degree of interconnection, one must be able to infer that the flow rate of water through the non-aquifer is very small relative to the flow rates through adjacent aquifers.

The following subsections present further guidance and examples on how boundaries between ground-water units are identified.

4.3.1 General Hydrogeologic Information Needed for Identifying Ground Water Units and Analyzing Interconnection

The information required to subdivide the ground-water regime into ground-water units generally includes topics within the fields of geology, hydrology, and management of ground-water resources (controls on withdrawals/recharge, properly abandoning deep wells, etc.). The description of the ground-water regime and any potential subdivisions must be as quantitative as possible. The Agency recognizes that the degree of precision with which the Classification Review Area can be subdivided is limited by the abundance and quality of readily available data. Supplementation of the existing data base with field and laboratory investigations both on-site and off-site may be needed to accurately confirm the existence of subdivisions. The following discussion will serve to guide the types of data collection efforts needed to justify the subdivision of the Classification Review Area.

Background information on geologic formations and occurrence/movement of ground water can be obtained at a regional scale of accuracy from State and Federal agencies. Topographic maps published by the U.S. Geological Survey (USGS) are now available at useful scales for most of the nation. These can help identify ground-water flow directions and flow divides for the uppermost aquifer. Data on the distribution and characteristics of soils are available from the USDA Soil Conservation Service. General information on precipitation, run-off and recharge rates can be obtained from the USGS and can be supplemented by climatic data from weather stations around the country. Ground-water pumpage and locations/depths of wells can generally be obtained from State agencies that issue well permits, or from local Public Health Agencies and water districts.

The first step is to identify all aquifers occurring within the ground-water regime of the Classification Review Area. In areas that have been well studied these will be recognized and documented in government agency reports. In poorly studied areas, proper recognition of aquifers can be inferred from lithologic descriptions of geologic formations, structural features of the area (if flow is mainly through fractured rock), and the depth and design of wells. The areal and vertical extent of hydrogeologic units within the ground-water regime can be shown in a series of cross-sections and maps. For most hydrogeologic settings it will be most useful to interpolate between locations where conditions are known (i.e., wells, outcrops, excavations, etc.) and present variations in thickness and elevations of important units with contour maps prepared at a common scale.

After the identification and graphical representation of the geologic framework it is possible to identify ground-water units within the ground-water regime using the guidance provided in subsequent sections.

4.3.2 Type 1 Boundaries: Ground-Water Flow Divides

The concepts of ground-water flow systems may not be familiar to some readers and needs to be reviewed in order to understand flow divide boundaries between ground-water units. Figure 4-3(a) shows in vertical cross-section a series of adjacent shallow ground-water flow systems for a single-layer, water-table aquifer. The systems are bounded at the base by a physical impermeable boundary. As is typical in humid regions, the water-table profile conforms to the topographic profile.

The flow net in Figure 4-3(a) clearly shows that ground-water flow occurs from the recharge area in the highlands to the discharge areas in the lowlands (i.e., valleys). Vertical line segments AB and CD beneath the valleys and ridges constitute ground-water flow divides, i.e., imaginary impermeable boundaries across which there is no flow. In the figure, these ground-water flow divides separate adjacent flow systems ABCD and ABEF which, for purposes of subdivision, correspond to ground-water units separated by Type 1 boundaries.

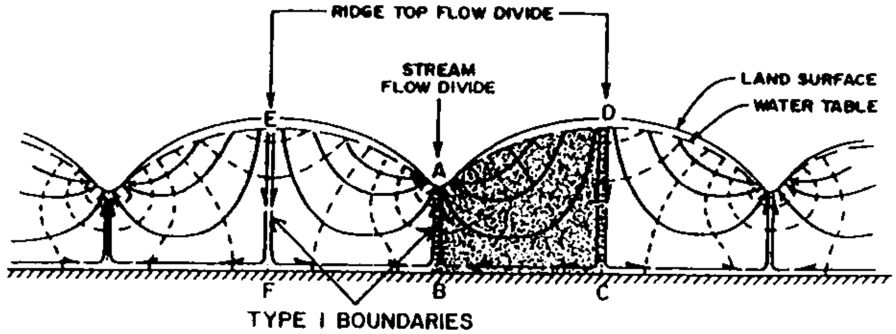
In simplified, symmetrical systems such as those illustrated in Figure 4-3(a), ground-water flow divides coincide exactly with surface water divides and extend vertically to the base of the aquifer. In more complex topographic and hydrogeologic settings these properties may diverge substantially from the situation illustrated.

A comparison of Figures 4-3(a) and 3(b) reveals how flow patterns and divides are altered when the undulations in the water table are superimposed on the regional hydraulic gradient towards a more regional stream and discharge area. Ground-water flow divides in Figure 4-3(b) extend through the full thickness of the aquifer only at either end of the entire flow regime. The full dimension of the flow regime may or may not be encompassed by the two-mile radius. The total length, S in the figures, can range from hundreds to thousands of feet.

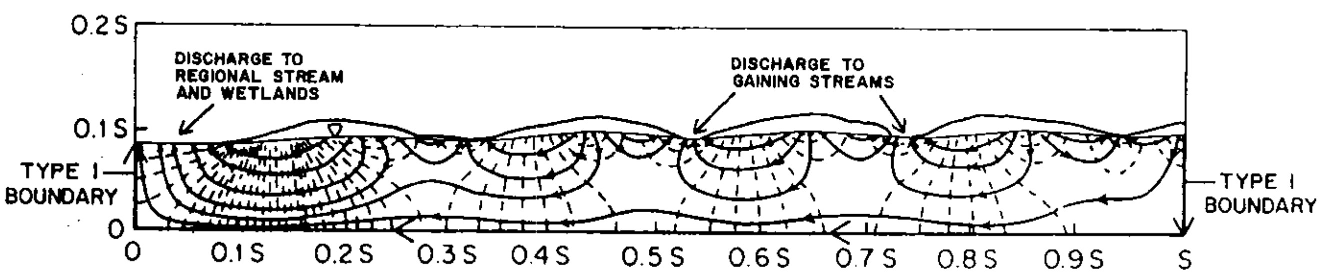
Figure 4-3(c) is an example of more complex conditions in which the flow patterns and flow systems are effected by both topography and regional variations in hydraulic conductivity of layered earth materials. Given adequate data, computerized models of real sites can provide approximations of ground-water flow patterns. In general, the level-of-sophistication employed to demonstrate the presence of a Type 1 boundary should be comensurate with the complexity of the hydrogeologic setting.

The spatial location of the water-table and ground-water flow divides may be stable under natural flow conditions but can be modified by man-made hydraulic stresses, such as large-scale ground-water withdrawals or recharge. In some cases it will be necessary to estimate the permanence (i.e., location with time) and position of ground-water flow divides under stressed conditions from available hydrologic and geologic data and foreseeable changes in water use.

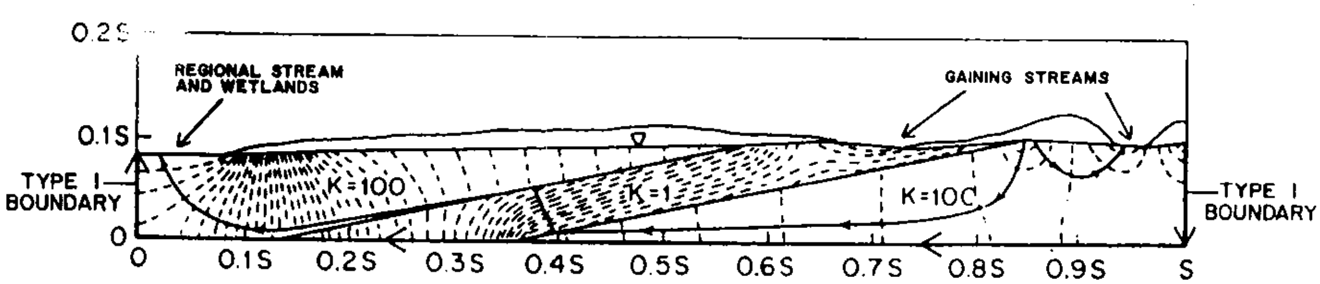
FIGURE 4-3
HYDROGEOLOGIC SECTIONS SHOWING FLOW SYSTEMS OF
INCREASING COMPLEXITY WITH TYPE 1 BOUNDARIES



a) Simple flow systems associated with a water-table aquifer (after Hubbert, 1940).



b) Ground-water flow pattern in a water-table aquifer with local and regional discharge areas (after Freeze and Whitherspoon, 1967).



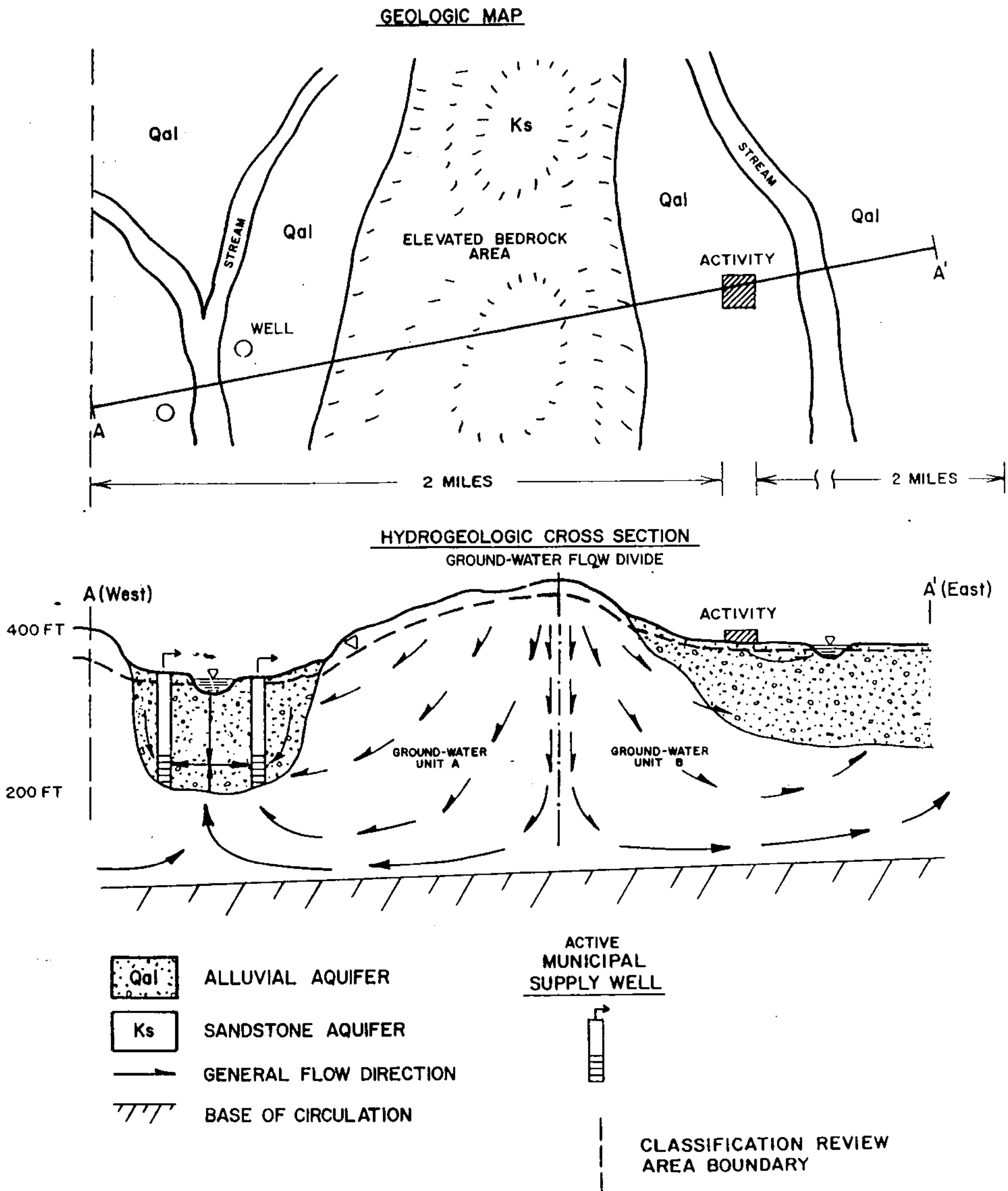
c) Ground-water flow pattern in dipping sedimentary rocks with local and regional discharge areas (after Freeze and Whitherspoon, 1967).

A good example of ground-water units separated by a Type 1 flow divide boundary is shown in Figure 4-4, The setting illustrated consists of two alluvial valleys with high-yield wells completed in sand and gravel deposits, separated by sandstone bedrock that can only provide limited supplies to domestic wells. Ground water in the alluvium is derived from precipitation and from the bedrock, and discharges to the river under natural conditions. Under pumping conditions, the water pumped by the high-yield wells is derived largely from the river, from local precipitation, and from the bedrock. Near the wells in the eastern valley, flow system boundaries are affected by ground-water withdrawals and are stable as long as the well discharges are steady. The ground-water flow divide separating the two valley aquifers is not effected by pumpage, and provides the essential characteristic that allows the delineation of ground-water units A and B.

In order to provide EPA with a defensible ground-water flow-divide delineation, a limited flow analysis will generally be required as a minimum. An acceptable approach is to prepare a water budget for the ground-water unit in order to show a reasonable order-of-magnitude balance on flow into and out of the system. This could involve the preparation of a ground-water flow net (see Glossary for definition) for the uppermost aquifer with accompanying estimates of volumetric flow into and out of the unit. The flow net can be generalized and need not be rigorously correct in a quantitative sense. The analysis should be carried out even though part of the ground-water system continues outside the Classification Review Area, that is, if part or all of the discharge or recharge area of the unit extends beyond the Classification Review Area.

The semi-quantitative flow net of the uppermost aquifer should be supplemented by a vertical hydrogeologic cross-section and supporting data showing that the uppermost aquifer is, in fact, underlain by an extensive aquitard or crystalline rock non-aquifer within the Classification Review Area. The flow net can be based on available water-table elevation data as interpreted from water levels in relatively shallow wells; locations/elevations of springs, wetlands, and perennial streams; and supplemented with topographic elevations. The rates and directions of flow can be estimated in plan view given a water-table contour map and estimates of aquifer thickness and hydraulic conductivity. The conductivity can be obtained from the area-specific reports, field or laboratory tests, or by estimating a range from the scientific literature based on earth material type. Flow patterns inferred from these data must also consider signifi-

FIGURE 4-4
EXAMPLE OF TYPE 1 FLOW DIVIDE BOUNDARY



cant spatial and directional variations in conductivity in areas having a more complex stratigraphic and structural geologic conditions.

At the beginning of the flow analysis, it is important to determine whether the ground-water flow system is in a state of steady or transient flow. Areas that are characterized by a lack of ground-water development and usage can generally be assumed to be in steady state. This will simplify the analysis because the estimate of system discharge can be equated to recharge. If the natural recharge rate compares favorably with a reasonable percentage of mean annual precipitation, the ground-water flow divides can be considered reliable. The applicant can go to the ground-water literature to obtain "reasonable" estimates to recharge in any geographic/ground-water region of the United States (e.g., see USGS Water-Supply Paper 2242 by R.C. Heath, 1984).

In areas characterized by large-scale withdrawals of ground water from shallow or deep aquifers, the flow regime is more prone to be in a transient state. Evidence of transient conditions includes:

- Declining ground-water levels
- Depletion of ground-water storage
- Movement of flow divides

When such evidence of movement exists, it may be necessary to estimate the ultimate steady-state position of the flow divides assuming conservatively large withdrawal rates and small water flow and storage properties.

4.3.3 Type 2 Boundaries: Low-Permeability Geologic Units

The Agency would assign a low degree of interconnection across the low-permeability geologic unit (Type 2 boundary) if the following conditions can be shown:

- The low-permeability geologic unit is laterally continuous beneath the entire area and/or limits the lateral continuity of the more permeable geologic unit

- There are no known wells, mine shafts, etc. that are improperly abandoned or unsealed through the geologic unit

- The geologic unit has a small permeability relative to both adjacent geologic units and to geologic media in general

- The flow of water through the geologic unit per unit area is insignificant relative to the flow of water per unit area through adjacent strata

Low-permeability geologic units include fine-grained sediments and sedimentary rocks, such as clays and shales, as well as crystalline igneous and metamorphic rocks that have few interconnecting fractures. Because these materials have small permeabilities, small quantities of water will be transmitted through them in response to hydraulic gradients. In areas where hydraulic heads beneath or within a low-permeability unit are greater than heads in an aquifer above the unit, the hydraulic gradient has an upward component across the Type 2 boundary. The Agency considers this to be the most favorable head relationship because it further ensures that the direction of ground-water movement at the boundary serves to inhibit the migration of contaminants into and across this type of boundary.

In selected environments, such as deep geologic basins, the applicant is free to make arguments that the flow of fluids is negligibly small through the low-permeability unit. The actual cut-off values of key variables such as permeability, thickness and hydraulic gradient are not specified in these guidelines and are left to professional judgments.

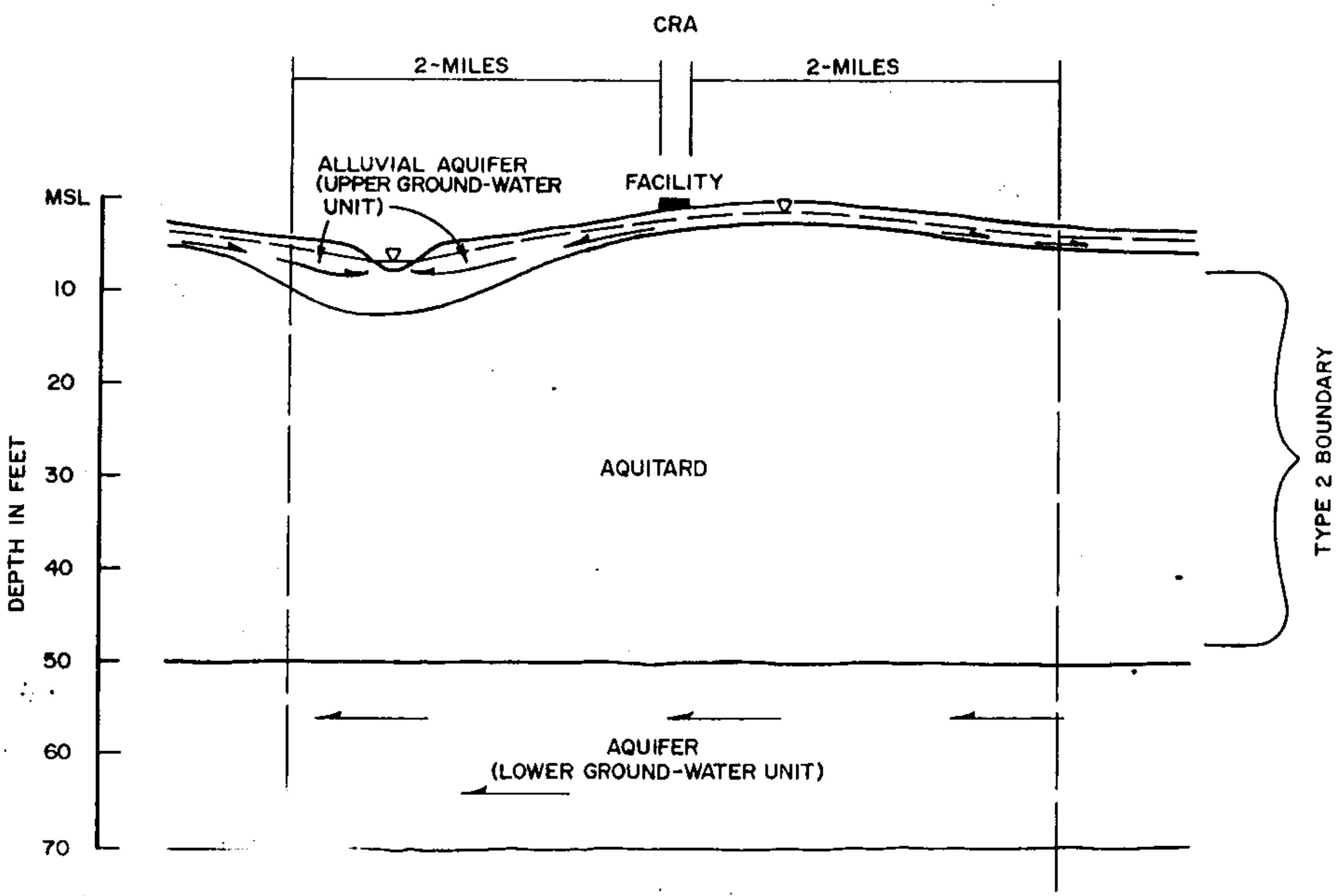
Figure 4-5 illustrates a setting where the presence of a thick, regionally extensive aquitard establishes a low degree of interconnection between a shallow ground-water unit and a deeper underlying ground-water unit (aquifer). This configuration is common in the Atlantic and Gulf coastal plain settings where the lower aquifer is the principal regional aquifer and is a source of water supply. It is overlain by an extensive confining clay that may be tens of feet thick. The shallow ground-water aquifer system supplies only limited amounts of water to wells. The reasons for the low interconnection between aquifers in this setting are as follows:

- the flow of water through the aquitard is exceedingly small,

- the time of travel of water through the aquitard is very large

Sedimentary basins commonly exhibit multiple freshwater aquifers each separated by a regionally extensive low-perme-

FIGURE 4-5
EXAMPLE OF TYPE 2 BOUNDARY



ability confining unit. Figure 4-6 is an example of such a basin where ultimate discharge of the deep fresh water through overlying low-permeability confining units (flow barriers) is to the ocean. Deeper ground waters in these basins will be characterized by a Total Dissolved Solids (TDS) concentrations that may be much greater than the 10,000 mg/l limit for Class III ground waters, and interconnection is considered to be low, even though hydraulic gradients are in the direction of less saline water.

The reasons for the low degree of interconnection are as follows:

- salts are retained in deep aquifers confined by laterally extensive aquitards,

- the flow of water through the confining units is exceedingly small,

- the time of travel through the confining unit is very large

- the depth to these waters is generally below the bottom of any major water-supply wells in the area.

Deep, confined, saline ground-water units with a low degree of interconnection to overlying fresh ground-water units are currently the primary hydrogeologic setting into which wells can be permitted to inject hazardous wastes under present EPA and state Underground Injection Control (UIC) regulations. These waters are herein defined as Class III, Subclass B ground water. EPA's position is that the interconnection test for such candidate Class IIIB waters will follow those tests for the UIC program, Class I wells.

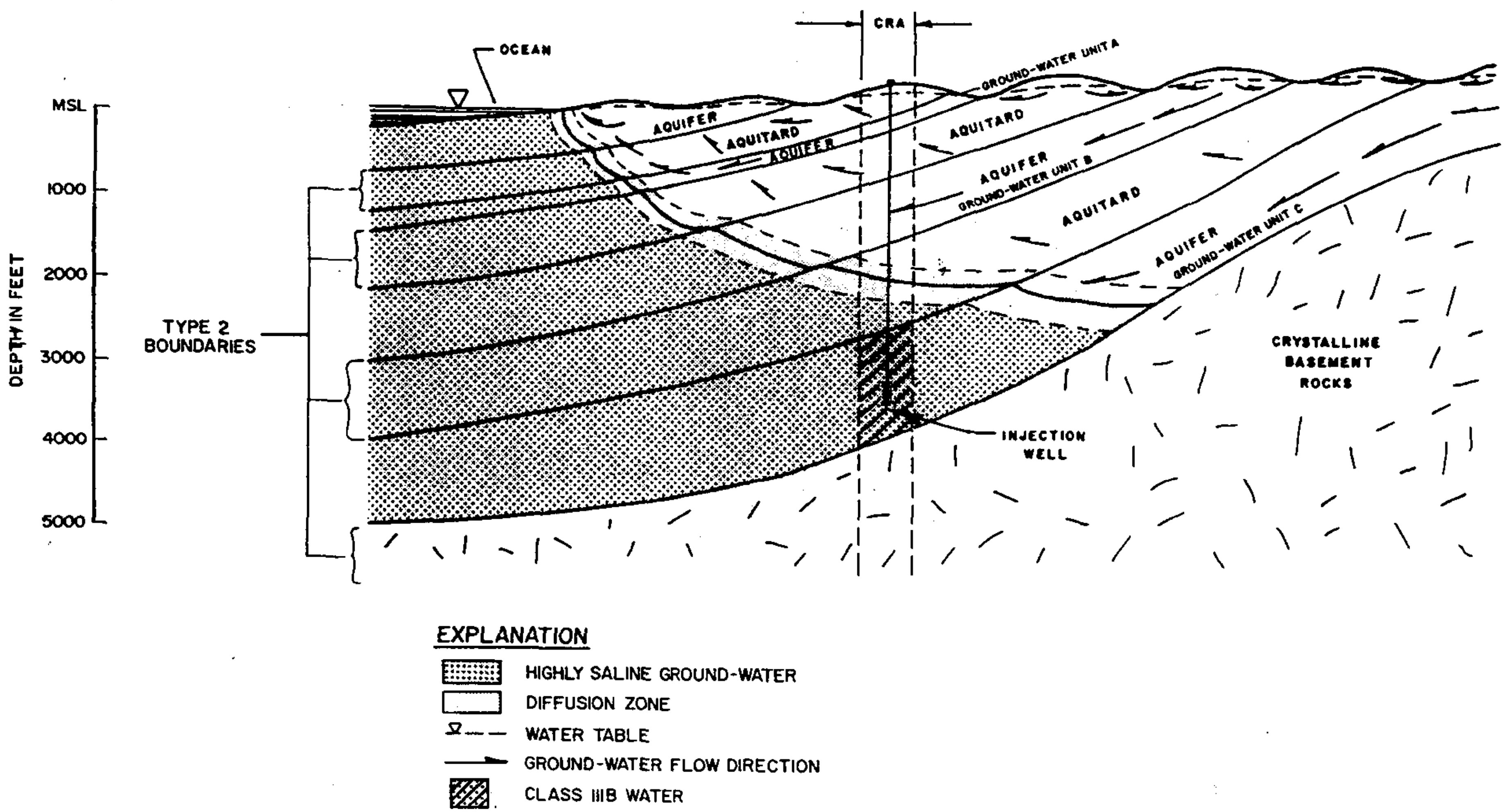
In general, the demonstration of the existence of a Type 2 boundary requires that one identify and characterize the laterally continuous low-permeability non-aquifer that constitutes the boundary. The following is a list of factors to be considered in making this demonstration:

- Stratigraphic setting and lithologic characteristics

- Structural setting and joint/fracture/fault characteristics

- Hydrogeologic setting and hydraulic head/fluid flow characteristics

FIGURE 4-6
EXAMPLE OF TYPE 2 BOUNDARIES BETWEEN AQUIFERS IN A SEDIMENTARY BASIN



The first distinction should be between whether the non-aquifer is of sedimentary or igneous/metamorphic origin. If it is sedimentary in origin, an identification of the environment of deposition will permit inferences about the expected geometry, thickness, and continuity of individual strata. These inferences should be defended with geologic sections including data from well logs and/or measured sections. The age of the unit, the degree of cementation, and degree of compaction are all qualitatively related to water-bearing characteristics (hydraulic conductivity and porosity).

If the unit is an igneous or metamorphic rock, the continuity and thickness can usually be inferred from geologic maps and reports for the region in which the Classification Review Area exists. Identification of igneous rocks that have tabular geometries such as volcanic flows, ash-fall deposits, or intrusive sills and dikes will allow inferences about thickness and continuity. These may serve as aquifers or aquitards within a sequence of sedimentary rocks. Crystalline "basement" rocks of igneous and metamorphic origin underlie the entire North American continent. In areas where these rocks are fractured and exposed at or near the land surface, they generally serve as poor-yielding aquifers. However, significant circulation can be assumed to be restricted to the upper few hundred feet because the fractures tend to close with depth. In other areas, where these rocks are buried by younger rocks, they can generally be assumed to represent the base of active circulation unless there is evidence to the contrary. In these situations the Type 2 boundary is equivalent to the bottom of the ground-water regime (see Glossary).

A general knowledge of the tectonic setting and structural geologic history of the region will provide insight into the types and frequency of geologic structures to be found in the Classification Review Area. Numerous field studies have shown that significant ground-water flow in consolidated sedimentary and crystalline rocks is controlled by geologic structures. These features include folds, faults and associated joints and fractures in the rock.

Major structures such as fault zones that intersect consolidated rock formations may hydraulically connect multiple aquifers into a system of aquifers. Fault zones in consolidated rocks are known to collect water from large areas and control the locations of ground-water discharge at major springs. In softer sediments and in some structural settings, fault zones can have the opposite effect by producing barriers to flow. Individual joints and small fractures in consolidated rocks and sediment can be mapped systematically with field studies, however, proof of their absence is the more important element in demonstrating the presence of a Type 2 boundary.

The best evidence of low-permeability non-aquifer conditions constituting a Type 2 boundary are those related to the hydrogeologic setting and measured hydraulic parameters. Table 4-2 shows that the hydraulic conductivity of both sedimentary deposits and igneous/metamorphic rocks can be estimated within several orders-of-magnitude on the basis of lithology alone. In parts of the United States associated with large ground-water usage, there has been a need to understand the ground-water regime and these areas will often have been studied by various government agencies. Consequently, the hydraulic properties of aquifers and aquitards will be known in quantitative terms. In these areas the thickness, lateral extent, and hydraulic conductivity will be documented. A favorable condition would then be associated with a recognized aquitard or aquiclude that is known to be relatively thick, homogeneous, widespread, and poorly permeable. The optimum head condition would be such that vertical hydraulic gradients are directed upward through the unit, i.e., across the Type 2 boundary.

4.3.4 Type 3 Boundaries: Fresh/Saline Water Contacts

Type 3 boundaries between bodies of ground water with contrasting concentrations of Total Dissolved Solids (TDS) most commonly occur within the following types of hydrogeologic settings:

- Sea-water intrusion into fresh-water aquifers in coastal regions,
- Saline waters associated with ancient evaporite deposits in sedimentary basins,
- Saline waters associated with closed topographic basins in arid regions.
- Saline brines in deep geologic basins,
- Geothermal fluids in tectonically active regions,

TABLE 4-2

RANGE OF VALUES OF HYDRAULIC CONDUCTIVITY AND PERMEABILITY

(AFTER FREEZE AND CHERRY, 1979)